RESULTS OF VERTICAL TESTS FOR THE KEK-ERL SINGLE CELL SUPERCONDUCTING CAVITIES

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Abstract

We have been developing L-band superconducting cavities for energy recovery linacs. In order to verify our design, we have fabricated two types of single cell cavities. One is a rather simple center-cell type cavity and another is an end-cell type single cell cavity which has complicated structures. After applying a series of surface treatment procedures, cavity performances were evaluated by way of vertical tests at 2K. A rotating mapping system with temperature and X-ray sensors were mounted on the cavities to make a diagnosis of the cavity behaviours. Results of vertical tests are described below. Both cavities satisfied the requirements against ERL cavities.

INTRODUCTION

The development of the superconducting cavity is one of the most important issues to realize high current energy recovery linacs (ERLs). Most challenging task is a strong damping of higher-order-modes (HOMs) to avoid beam-breakup instabilities and to suppress heat loads on cryomodules.

Fig. 1 shows a conceptual view of the KEK-ERL model-2 cavity [1-4], which has been designed for ERL project in Japan [5]. Frequency is 1.3 GHz. Acceleration gradient of 15-20 MV/m is required under CW operations. Field emission free cavities are desirable to avoid dark current and cryogenic losses. Its features are the following.

- Cell shape is optimized and large iris diameter of 80 mm is chosen to suppress HOMs.
- Eccentric-fluted beampipe is adopted to suppress quadrupole HOMs.
- HOMs propagate through the large beampipes and are absorbed by microwave absorbers mounted on both sides of the cavity.

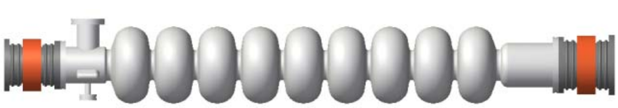

Figure 1: Conceptual view of the KEK-ERL model-2 cavity

As a first step, before examining a 9-cell cavity, we have fabricated two types of single-cell cavities to confirm the validity of its unique designs. After applying a series of surface treatments, we have carried out vertical tests for these cavities to evaluate their high power performances. The results are described below.

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SINGLE CELL CAVITIES

We have fabricated two types of niobium L-band single cell cavities. One is called as “C-single” cavity, whose cell shape is same as that of center-cells. Its iris diameter is 80 mm and an elliptical shape is applied for equator region. The cell diameter is 206.6 mm. Beampipes, with 80 mm diameter, were attached to the both side of the cell. Its main aim is to test the newly designed cell shape.

Another is called as “E-single” cavity, which is a combination of the both end of KEK-ERL 9-cell cavity. Its cell shape is different from the one of the center-cell, because of the adjustment of frequencies to 1.3 GHz. Its iris diameter is 84 mm. The taper sections connect the irises to the large beampipes of diameter 100 and 120 mm. The eccentric-fluted structure, input and pickup ports are also reproduced. Motivation of this cavity is to examine such complicated structures. For both cavities, all of electron-beam-welded parts have 2 mm straight sections. These cavities can be seen in Fig. 2.

Figure 2: C-single (left) and E-single cavity (right)

SURFACE TREATMENTS

We have applied a series of surface treatments, which are listed in Table 1, against C-single and E-single cavities. These procedures are basically come from a KEK recipe for superconducting cavities, but some details are different.

Electron-beam-welded equator and iris parts were buffed with #400, in order to avoid the multi-pactings and field emissions caused by the welding defects. Wet-type and dry-type centrifugal barrel-polishing were applied for C-single and E-single, respectively. It is found that the wet-type barrel-polishing has an ability to remove thicker surface. After 100 μm electropolishing (EP), the cavities were annealed at 750 degree to eliminate hydrogen. Finally, cavities were electropolished by 20 ~ 30 μm, cleaned up by the high-pressure- rinsing (HPR) and assembled for the vertical testing. The assembled cavities were baked at 130 degree. The treatments of EP and HPR had been performed at Nomura Plating Co., LTD.

As listed in Table. 1, additional final EP of 30 µm, followed by HPR, assembly and baking, was applied to E-single cavity before fourth vertical tests.

Table 1: List of the surface treatment for both cavities

	C-single	E-single
Buffing	Electron-beam-welded parts were buffed by #400	
Barrel-polishing	60µm (wet)	10µm (dry)
EP-1	100µm	100µm
Annealing	750 degree, 3hours	
Final EP	20µm	30µm +30µm(before 4^{th} vertical test)
HPR	8 MPa, 1.5hours	
Baking	130 degree, 12~24hours	

EXPERIMENTAL SETUP

Vertical tests were performed at KEK-D10 experiment power station area, where there is a cryostat, for L-band single cell cavity measurements, whose diameter is 350 mm and depth is 2.1 m. A pumping power of the system is 5500 litter/min. The cryostat and pumping system is shown in Fig. 3.

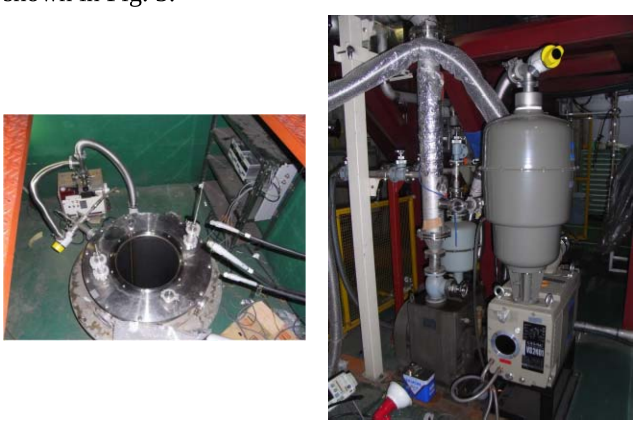

Figure 3: cryostat at KEK-D10 area (left) and its pumping system (right).

A signal generator of HP8663A is used as an oscillator. Frequency feedback is controlled by detecting phase difference between forward and reflected or transmitted signals using a double balanced mixer, WJ M2BC. Frequency is measured by a frequency counter, Agilent 53181A. Forward, reflected and transmitted powers are measured by power meters, Agilent E4418B/E4419B, with carful calibration of cable losses and insertion losses. Temperature of the cavities is measured by using Si and Ge sensors. An oscilloscope of Tektronix DPO4140 is used for decay time measurements.

Rotating mapping system was mounted on the cavities as shown in Fig.4. This mapping system consists of carbon resisters and Si PIN photo diodes and can measure temperature rise and radiated X-rays, respectively. This sensor array can rotate around the cavity axis, thus it is possible to observe information all around the cavity surface. Details of the system are described in ref [6]. A movable coupler system is applied. It covers two order of external Q value to obtain matching conditions between 4K and 2K measurements.

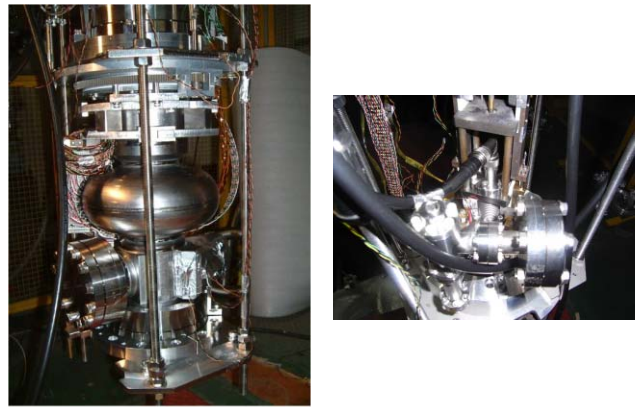

Figure 4: Rotating mapping system mounted on E-single cavity (left) and the movable input coupler on C-single cavity (right).

RESULTS OF VERTICAL TESTS

Followings are the results of the vertical tests for C-single and E-single cavities.

Results of C-Single Cavity

C-single cavity was measured two times. No surface treatments were done between these measurements. The results of Q-E measurements, at 2K and 4K, are shown in Fig. 5. It shows excellent performances. Accelerating gradient reached to 37 MV/m at 2K. There was no indication of field emissions. There were some quenches, but they were easily processed. Limitation of the field was a temperature rise due to the lack of the pumping power. Unloaded Q (Q_0) of 10^{10} can be kept at 22 MV/m. These results confirm the validity of this new cell shape.

The limitation for the 4K measurements is also the temperature rise due to the lack of the pumping power. No difficulties were observed.

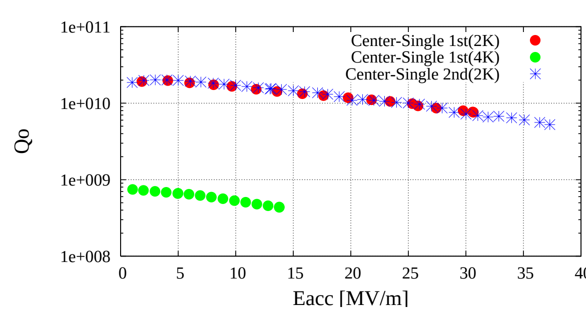

Figure 5: Results of vertical tests for C-single cavity

Results of E-Single Cavity

E-single cavity was measured four times. Measured Q-E performance is shown in Fig. 6.

At first measurement, maximum accelerating gradient reached to 23 MV/m, but there were field emissions from 15 MV/m and Q_0 drop was seen. Accelerating gradient was limited by thermal quenches, which was caused by field emissions. There were some quenches, which could be processed, during the test. But the final one could not be processed.

After the first test, we re-baked the cavity at 130 degree during 12 hours and tried second vertical test. However, there was a trouble at the movable input coupler. The tip of the coupler touched to the cavity surface and it was impossible to get matching condition. Thus, no reliable data could be taken. After second test, we broke the cavity vacuum and exchanged the troubled input coupler to a new one. At this time, no surface treatment has been applied, except baking at 130 degree for 12 hours.

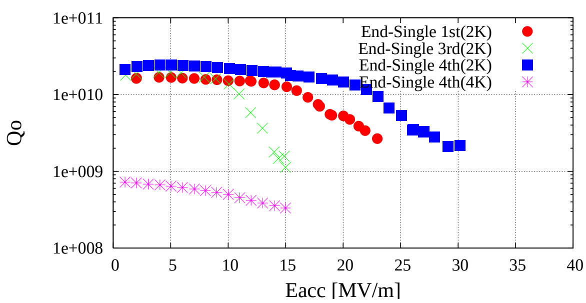

Figure 6: Results of vertical tests for E-single cavity

At third measurement, investigations were focused on the data taken by the rotating mapping system. As expected, E-single cavity was suffered from strong field emissions from low voltage, since no surface treatment has been applied. Field emission started at 10 MV/m and acceleration gradient was limited at 15 MV/m. Limitation is thermal quenches due to the field emissions. The mapping system could take interesting data, which shows clear temperature rise and some X-ray peaks.

After this measurement, additional final EP of 30 µm and HPR of 1.5 hours, was applied to clean up the cavity surface. The cavity was re-assembled for the vertical test and baked again at 130 degree during 12 hours.

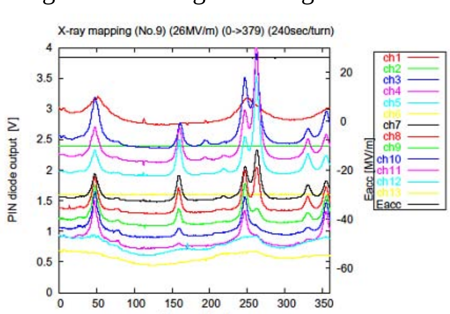

Figure 7: X-ray mapping data at 26 MV/m

At forth test, still the field emissions were observed, but much improved from previous measurements. Maximum field reached to 30 MV/m. Again, limitation is the thermal quenches caused by field emissions. As an example, X-ray mapping data, at 26 MV/m, is shown in Fig. 7. Many X-ray peaks caused by field emissions can be clearly seen. Obtained mapping data indicated that the structures such as eccentric-flute and ports were not the sources of these emissions. Unloaded Q of 10^{10} can be kept at 23 MV/m. Below 20 MV/m, there were no signal of field emissions. This result satisfies the requirement against the ERL cavities.

The limitation for the 4K measurements was the temperature rise due to the lack of the pumping power. No difficulties were observed also for E-single case.

Results of Rs - 1/T Measurements

Fig. 8. shows the results of Rs-1/T measurements for C-single and E-single cavities. These data was taken at the acceleration gradient of 1.5~2.0 MV/m. Since there was only few data at below 2K, it is rather difficult to estimate an accurate residual resistance. It is expected, roughly estimated, to be 10~15 nΩ.

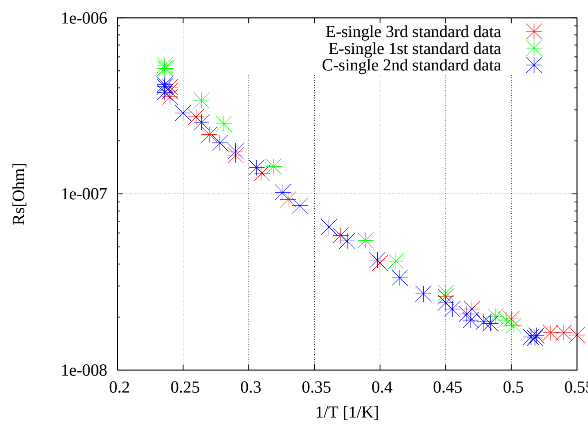

Figure 8: Rs vs 1/T for C-single and E-single cavities

SUMMARY

We fabricated two types of single cell cavities, C-single and E-single cavities. After a series of surface treatments, their performances were investigated by way of vertical tests at 2K and 4K. C-single and E-single cavities reached to 37 MV/m and 30 MV/m, respectively. No field emission signals were observed below 20 MV/m at final condition. These results satisfy the requirements to ERL cavities. The rotating mapping system worked fine. Clear emission signals, such as X-ray peaks and temperature rise, were observed. Encouraged by these results, we are now proceeding for a nine-cell KEK-ERL cavity.

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